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Effects of Amplitude Compression on Relative Auditory Distance Perception

by Ashley Foots

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A reprint from Towson University's Office of Graduate Studies, Department of Audiology, Speech-Language Pathology, and Deaf Studies, Towson, MD, May 2013.

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14. ABSTRACT
Military C&HPS use amplitude compression to provide protection and prevent distortion which has the potential to affect relative auditory distance perception by reducing the level differences between sounds. The focus of the present study was to investigate the effect of amplitude compression on relative auditory distance perception.
Impulse responses were recorded through KEMAR and convolved with pink noise and a dog bark to create stimuli. Two levels of amplitude compression were applied to the recordings through Adobe Audition sound editing software to simulate military C&HPS.
Data were collected in 12 conditions based on combinations of three independent variables: reference distance (6.5 ft, 16.5 ft), stimulus (pink noise, dog bark) and compression (none (linear), low, high). Participants listened to the stimuli through insert earphones in a 2IFC adaptive task and selected the stimulus they perceived to be farther away. As the participant selected the correct stimulus, the computer program reduced the separation in the next trial. The dependent variable was the smallest average separation in distance across 3-5 runs.
A 3-factor Analysis of Variance showed significant main effects of distance and compression as well as significant interactions between the three variables. Follow-up analyses within each stimulus indicated that the effects of compression varied between v the two stimuli. For both stimuli, listeners needed increased separation as the compression level increased. For the pink noise, the effect of compression was greater for the 6.5 ft distance than the 16.5 ft distance. For the dog bark stimulus, the low level of compression affected perception greater at the 6.5 ft distance than at the 16.5 ft distance.

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Ashley Foots

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This is to certify that the thesis prepared by Ashley Foots entitled Effects of Amplitude Compression on Relative Auditory Distance Perception has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree Doctor of Audiology.

Stephen Pallett, Au.D. — 4/22/13
Chair, Thesis Committee — Date

Paula Henry, Ph.D. — 22 April 2013
Co-Chair, Thesis Committee — Date

Brian Kreisman, Ph.D. — 4/22/13
Co-Chair, Thesis Committee — Date

Janet V DeLany

Janet DeLany, D.Ed. — 5/11/13
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Abstract

Relative auditory distance perception is when a listener is able to distinguish the distances of two or more sounds. An individual's ability to judge relative auditory distance for sounds primarily depends on the overall level differences between sounds. Military C&HPS use amplitude compression to provide protection and prevent distortion which has the potential to affect relative auditory distance perception by reducing the level differences between sounds. The focus of the present study was to investigate the effect of amplitude compression on relative auditory distance perception.

Impulse responses were recorded through KEMAR and convolved with pink noise and a dog bark to create stimuli. Two levels of amplitude compression were applied to the recordings through Adobe Audition sound editing software to simulate military C&HPS.

Data were collected in 12 conditions based on combinations of three independent variables: reference distance (6.5 ft, 16.5 ft), stimulus (pink noise, dog bark) and compression (none (linear), low, high). Participants listened to the stimuli through insert earphones in a 2IFC adaptive task and selected the stimulus they perceived to be farther away. As the participant selected the correct stimulus, the computer program reduced the separation in the next trial. The dependent variable was the smallest average separation in distance across 3-5 runs.

A 3-factor Analysis of Variance showed significant main effects of distance and compression as well as significant interactions between the three variables. Follow-up analyses within each stimulus indicated that the effects of compression varied between

the two stimuli. For both stimuli, listeners needed increased separation as the compression level increased. For the pink noise, the effect of compression was greater for the 6.5 ft distance than the 16.5 ft distance. For the dog bark stimulus, the low level of compression affected perception greater at the 6.5 ft distance than at the 16.5 ft distance.

Amplitude compression as used in military C&HPS can negatively affect a user's ability to determine the distance relationship between two sounds, particularly when higher levels of compression are used. Care should be taken to ensure that the use of amplitude compression does not significantly affect auditory perception.

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Chapter 1

Introduction

Auditory distance perception is the ability to perceive how far away a sound is from the listener. Distance perception is not as well researched as the primary skill of spatial hearing: localization (Blauert, 2001; Zahorik, Brungart, & Bronkhorst, 2005). There are two aspects of auditory distance perception. The first aspect is absolute auditory distance perception, knowing the precise distance of a sound. The second aspect is relative auditory distance perception, knowing the distance relationship between two or more sounds. An individual’s ability to successfully perceive absolute and relative auditory distance for sounds arriving in front of them depends on several cues. These cues include the overall level of the sound or sounds, the ratio between the direct sound and the indirect sounds (reverberation), the frequency spectrum of the sound (how much high frequency information is contained in the stimulus) and the listener’s familiarity with the stimulus (Coleman, 1963; Mershon & King, 1975; Zahorik et al., 2005). Of these cues, overall level has been documented as the primary cue for relative auditory distance perception.

Military communication and hearing protection systems (C&HPS) are used to provide three auditory capabilities in a single device: hearing protection, radio communication and talk-through capability. C&HPS utilize amplitude compression in their signal processing in order to provide hearing protection while preventing distortion of high-level sounds. Amplitude compression in C&HPS has the potential to affect

absolute and relative auditory distance perception by altering the overall level of a sound as well as the differences in levels of two or more sounds.

The focus of the present study was to investigate the effects of amplitude compression on relative auditory distance perception for sounds arriving from directly in front of the listener.

Chapter 2

Literature Review

Researchers have assessed spatial hearing in humans; however, auditory distance perception is not as well researched as auditory localization (Blauert, 2001; Zahorik, Brungart, & Bronkhorst, 2005). Auditory distance perception is the ability to perceive how far away a sound is from the listener. The two aspects in auditory distance perception are knowing the precise distance of a sound (absolute auditory distance perception) and knowing the spatial relationship of two or more sounds (relative auditory distance perception). For example, if an individual hears a dog bark and a police siren either at the same time or in sequence, the listener can perceive absolute or relative auditory distance perception. Amplitude compression could affect a listener's auditory distance perception by changing the intensity level of one or both sounds as well as changing the perceived separation of the two sounds by decreasing the difference in their respective levels. The focus of the present study will be the effect of amplitude compression on relative auditory distance perception.

Stimulus Cues

There are several stimulus cues that play a role in an individual's ability to judge both absolute and relative auditory distance for sounds arriving from directly in front of them. These stimulus cues consist of the overall level, the ratio between the direct sound and the indirect sounds due to the presence of reverberation, and the frequency spectrum (how much high frequency information is contained in the stimulus) (Coleman, 1963; Mershon & King, 1975). The overall level of the sound is used to assign the approximate distance of a sound by labeling lower level sounds as farther away and higher level

sounds as closer to the listener. Overall level is a primary auditory distance cue; whereas, the direct-to-reverberant ratio and the frequency spectrum of the stimulus are considered secondary cues. A listener's familiarity or experience with a stimulus can also improve his or her ability to accurately determine its distance in space (Coleman, 1962). If individuals are familiar with the stimulus they can use prior knowledge of auditory cues that are associated with that sound (i.e., what it sounds like at different distances) to determine the distance. For instance a dog bark should be of a certain intensity level at a certain distance and a lower intensity at a greater distance. For absolute auditory distance perception the overall level is only beneficial if the individual has prior experience with the sound. If a person has no experience with dogs, it will take them some time to learn what a typical level is at a particular distance. However, at least in the U.S., experience with dog barks is quite common. In contrast, for relative auditory distance perception the individual does not necessarily need prior experience with the sounds because the relationship between the intensity levels of the sounds will be compared by the listener and assigned appropriate locations. Several researchers have investigated the contributions of these cues to determine auditory distance perception.

Primary cue

It has been suggested that overall level is the primary cue used to determine the absolute distance for sounds that a listener has experienced multiple times (Coleman, 1962; 1963; Gardner, 1969). The inverse square law states that the sound pressure level decreases by 6 dB for every doubling of distance. This means that as the distance between an individual and a sound source increases, the level of the sound arriving to the

listener will decrease. Listeners will perceive a lower level sound to be farther away than a higher level sound. There are several studies that support this phenomenon.

Gardner (1969) examined absolute auditory distance perception with live and recorded speech signals that were either whispered or shouted. The researchers hypothesized that shouted speech would be perceived as far away and whispered speech as close since humans whisper when they are close and shout when they are far away. These signals were presented from loudspeakers and talkers located at various distances ranging from 3 to 30 ft. In agreement with their prediction, individuals overestimated the distance of the shouted speech signal (perceiving it to be farther away than it was) and underestimated the distance of the whispered speech signal (perceiving it to be closer than it was).

Mershon and King (1975) investigated auditory distance perception in a reverberant tunnel (experiment 1) and in an anechoic chamber (experiment 2). For Experiment 1, two 5-sec presentations of white noise at intensity levels of 50 and 60 dBA were presented to listeners through two loudspeaker locations, a near loudspeaker located 2.74 m from the participant and a far loudspeaker located 5.49 m (twice the distance) from the participant. Half of the participants were presented with the two stimuli from the near loudspeaker and the other half from the far loudspeaker. In Experiment 2, in the anechoic environment, a series of six 5-sec presentations of white noise were used. Between the first and second burst and the fifth and sixth burst, the level of the noise was changed so that two bursts were at one level and four were at a different level. In both experiments, the task was the same. The participants were asked to indicate the absolute distance of each sound. The authors found that in both experiments, individuals perceived

the 60 dBA sound stimuli as being closer (presumably because it was higher in overall level) regardless of whether the sounds were presented from the near loudspeaker or the far loudspeaker. The environment with greater reverberation resulted in participants perceiving the sound as being farther away as compared to the anechoic environment. However, in both experiments, listeners always judged the lower intensity sound as being farther away than the higher intensity sound, supporting the notion that overall level is a primary cue for distance.

A study completed by Strybel and Perrott (1984) investigated a listener's ability to judge the relative distance of a sound source in comparison to a reference sound source. The reference sound sources were located 49, 152, 304, 609, 1219, 2438 or 4876 cm from the participant. The authors used a 500 msec broadband noise burst at a single intensity level of 65 dBA from a reference speaker with a 500 msec break and then a second 500 msec noise burst from a movable speaker. In this experiment, participants made relative auditory distance judgments (identifying which sound was farther than, equal to, or closer than the reference stimulus) presumably based on intensity differences between the pairs of sounds with softer sounds being identified as farther away than louder sounds. As was shown in Mershon and King (1975), when individuals heard two sounds at different levels, the higher level sound was perceived as closer than the lower level sound. Clearly, the overall level of a stimulus plays a large role in auditory distance perception, but other cues are also important.

Secondary cues

Secondary auditory cues include the listener's experience or familiarity with a given stimulus, the amount of reverberation present in the stimulus and the high

frequency content of the stimulus. Each of these cues and the evidence supporting their importance is discussed below.

The ability to accurately judge absolute auditory distance perception is poor during initial exposure to unfamiliar sounds (Coleman, 1962; Mershon & King, 1975). If an individual is presented with an unfamiliar sound, he or she can use only limited auditory cues to perceive distance. What is familiar to one person may not be familiar to another. For example, most people know what a gunshot sounds like; however, only select individuals would be able to identify the specific type of gun that produced the sound. As individuals become more familiar with sounds (through repetition), they learn about the auditory cues associated with each sound at different distances. There are two researchers who have investigated the effect of the listener's familiarity with a stimulus in relation to absolute auditory distance perception.

Coleman (1962) implemented a study in which loudspeakers were placed at various distances in front of listeners who judged which loudspeaker was the source for a wide-band random noise (considered to be an unfamiliar stimulus). There were 100 trials collected on each participant with no training or feedback provided. The first trial resulted in inaccurate judgments of auditory distance, but over time the participants improved in their distance perception accuracy. In contrast, some studies have used a familiar stimulus in order to achieve a more real-world listening environment. As mentioned earlier, Gardner (1969) used a speech stimulus and showed that listeners were more accurate in their distance estimates. Comparing Coleman (1962) and Gardner (1969), these two studies suggest that individuals will judge the distance of a familiar sound more accurately than an unfamiliar sound.

In addition to stimulus familiarity, Coleman (1962) introduced the direct-to-reverberant ratio as a cue to judge auditory distance. The direct-to-reverberant ratio is the relationship between the direct and reflected sound energy within the area of the original sound source (Emanuel & Letowski, 2009). Reverberation occurs in an environment that has reflective surfaces. As previously mentioned, sound decreases in level as an individual moves farther away from a sound source. However, in an environment with reflective surfaces the sound pressure will decrease less with increases in distance due to the sound bouncing off of nearby surfaces. The reflective surfaces can add energy back to the sound's level and result in a perception that the sound source is closer than it actually is. The direct-to-reverberant ratio will be larger for sounds in less reflective environments and smaller in more reflective environments. Several studies support the direct-to-reverberant ratio as a cue to auditory distance perception.

One of the findings in the Mershon and King (1975) study was the influence of reverberation in relative auditory distance estimates. Recall that the investigators had participants estimate the distance to sounds of different intensities in two environments: an anechoic chamber and a reverberant tunnel. An analysis of the patterns of results showed that regardless of intensity level of the noises presented, and the fact that the two loudspeakers were at the same distances, stimuli presented in the anechoic chamber were always perceived as being closer than those in the reverberant environment. The investigators hypothesized that the differences in perceived distance were likely due to the absence of reflections in the anechoic chamber which were present in the tunnel.

Mershon and Bowers (1979) completed a study investigating the effects of reverberation and familiarity with the environment which was a follow on to a previous

study in their laboratory (Mershon and King, 1975). Participants were blindfolded and located in a hard walled reverberant room. The participants had to judge the distance from which a broadband stimulus originated. Loudspeakers were located directly in front of them as well as 90 degrees to the side at distances of .55 to 8 m. The participant reported the perceived distance of the stimulus in ft and/or in. From the trials in which stimuli were presented from directly in front of the listener, results indicated that participants perceived the nearer sounds as farther away (overestimated their distance) and perceived the farther sounds as nearer than they were (underestimated their distance). The authors cautioned that these conclusions were only true for the reverberant environment that was tested.

The high frequency content of a stimulus also provides information to the listener regarding the distance of the source. The frequency spectrum of a sound will change as the sound wave travels over distance (Coleman, 1968). High frequency components in a sound will decrease as the sound travels due to absorbing properties of the air and surrounding materials. Loss of high frequency content in a broadband stimulus will cause an individual to perceive the sound as being farther away than it actually is. Blauert contends that atmospheric absorption that leads to a decrease in high frequencies with increases in distance begins to occur at 15 m (Blauert, 2001). Several researchers have investigated the available frequency spectrum of a sound and its effect on auditory distance perception (Coleman, 1968; Blauert, 2001; Little, Mershon, & Cox, 1992).

One of the studies, Little et al. (1992), provided results from an investigation of the effects of spectral content on distance perception among similar sounds. Blindfolded participants made absolute and relative auditory distance judgments of stimuli that were

manipulated using high-pass and low-pass filters. Participants made judgments of stimuli that were unfiltered followed by stimuli that were filtered. Following the presentations of the filtered stimuli, participants made a second judgment on the original unfiltered sounds. Results suggested that when there is a decrease in high frequency information the sound will be perceived as being farther away due to the loss of high frequency content in the stimulus (Little et al., 1992). The results of this study suggested that when individuals are exposed to a broadband stimulus with high frequency components, they perceive the sound as being closer than a broadband sound without high frequency components.

All of the cues for auditory distance perception work in combination in order for a listener to accurately perceive the distance of a sound source. As previously mentioned several studies have demonstrated that the primary cue for relative auditory distance perception is the overall level of the sound.

Primary Cue for Relative Auditory Distance Perception

The differences in level between two or more signals are the primary cues used for relative auditory distance perception (Mershon & King, 1975). Softer sounds are perceived as originating from greater distances than louder sounds, and when one sound is lower in intensity than another it will be perceived as the farther of the two sounds. If level differences were the only cue used for auditory distance perception then the separation of the two sounds in ft or in could be predicted based on the known just noticeable difference (jnd) for level which remains constant across intensity (Jesteadt, Wier, & Green, 1977; Miller, 1947). The hypothesis behind the ability to predict a listener’s perception of relative auditory distance perception based on level differences is

known as the pressure-discrimination hypothesis (Ashmead et al., 1990). Furthermore, this jnd would remain constant at various reference points.

Miller (1947) found that individuals can detect a change in intensity between .3 and .5 dB. This means that individuals can detect differences in sound pressure and discriminate between two sounds as long as the two sounds differ by at least .3 to .5 dB in intensity.

Furthermore, Jesteadt et al. (1977) completed a study investigating intensity discrimination over a range of frequencies and intensity levels. Results indicated that approximately a 1 dB difference was needed across all frequencies to establish a jnd when listening to sounds at a comfortable level. A smaller jnd was found for higher sensation levels. The results of Jesteadt et al. (1977) agreed with results reported by Miller (1947) who used a random noise. Jesteadt et al. (1977) and Miller (1947) demonstrated that the jnd for changes in level remains (essentially) constant.

In order for the pressure-discrimination hypothesis to hold true, the calculations in separation distance must be made that would yield differences in intensity between two sounds on the order of .3 to 1 dB. The minimum separation between two sounds that will yield this difference is along the order of a 5% change in distance from the original reference point (Ashmead et al., 1990).

Two studies have investigated jnds for relative auditory distance perception based on various auditory cues (Ashmead et al., 1990; Stybel & Perrott, 1984). In both studies, the jnd was measured as the minimal separation in space for the listener to correctly identify which sound was closer or further away. These studies reported different patterns of jnd across distance. The Ashmead et al. (1990) study showed a fairly constant jnd

across a range of 1 to 2 m. In contrast, the study by Strybel and Perrott (1984) measured jnds for sound source separation and showed that they varied depending on the reference distance. Therefore, although intensity may be the primary cue for relative auditory distance perception, it cannot be the only cue; other cues influence it as well.

Ashmead et al. (1990) had participants seated in an anechoic chamber and determine which of two sounds was closer to them. There was a stationary loudspeaker and a mobile loudspeaker that were both used to present a 100-8000 Hz broadband stimulus (in random order not simultaneously) with a 1.2 s silence between the sounds. The stationary loudspeaker was the reference loudspeaker and was at either 1 or 2 m. All participants were tested from both reference distances. The mobile loudspeaker was physically moved by the experimenter in between each trial. Participants completed a practice trial with feedback provided. Results at 1 m indicated a 5.73% jnd while results at 2 m indicated a 5.91% jnd, suggesting a fairly consistent jnd within the range of 1 to 2 m.

Stybel and Perrott (1984) had participants sit in the middle of an athletic field in an elevated chair while they were blind folded. The chair was adjusted as needed so the participant’s ears measured 180 cm from the ground. The chair was placed at one of seven possible distances (9, 152, 304, 609, 1219, 2438, and 4876 cm) from the reference point. A 500 msec noise burst was presented from a reference speaker followed by a 500 msec rest and then a 500 msec noise burst was presented from a moveable loud speaker. There was then a 1500 msec break followed by a repetition of the sequence. The participants’ task was to determine if the stimulus was farther than, equal to, or closer than the reference stimulus. Stybel and Perrott (1984) reported a jnd for distance of 9%

for a reference distance of 3 m and a jnd for distance of approximately 6% for reference points ranging from 6-49 m.

Although Ashmead et al. (1990) showed a consistent jnd across close distances in an anechoic chamber, Strybel and Perrott (1984) reported different jnds depending on reference distance. Furthermore, the jnd measured by these two studies differed from just under 6% for the Ashmead study to 9% in the Strybel and Perrott study. These studies failed to demonstrate consistent jnds for different reference distances in contrast to what would be predicted if level differences alone were the driving cue for relative auditory distance perception.

Communication and Hearing Protection Systems

As stated previously, C&HPS provide three auditory capabilities: radio communication, hearing protection and environmental hearing. Soldiers (as well as firefighters, police officers, etc.) use C&HPS to allow for the three auditory capabilities. C&HPS have a talk through option where environmental sounds are provided to the wearer through microphones mounted on the outside of the system.

There is limited information in the literature regarding auditory perception with C&HPS. In general, work has been done with hearing protective devices (HPDs) in isolation and these devices have been shown to have a negative effect on listening abilities. However, hearing protection is only one aspect of the C&HPS. The primary aspect of HPDs and C&HPSs that has been examined is auditory localization. The use of HPDs has been found to be detrimental for auditory localization. Similarly, C&HPS have been found to be detrimental for auditory localization when used as HPDs.

Casali, Ahroon, and Lancaster (2009) compared three commercially available C&HPS: the Combat Arms Earplug (a passive, non-linear earplug that allows for audibility of low level sounds but protecting against impulse noises), the Communication Enhancement and Protection System (an electronic device that provides radio communication and protection from loud sounds), and the Peltor Com-Tac II® (an electronic circumaural-style earmuff). The devices were compared in two mission scenarios used as training exercises: reconnaissance of an enemy camp without enemy engagement and a raid on an enemy camp with enemy engagement. The results indicated that all systems negatively affected listening abilities over what would be perceived with an open ear (Casali et al., 2009).

Talcott, Casali, Keady, and Killion (2012) conducted an outdoor auditory localization study to determine how well listeners could determine the location of a gunshot. Listeners completed the task with four C&HPS (Peltor Com-Tac II®, Etymotic EB 1 High-Fidelity Electronic BlastPLG earplugs™, EB 15 High Fidelity Electronic BlastPLG earplugs™, and 3M Single-Ended Combat Arms Earplugs®) and an open ear condition. Although there was no significant difference between the earplugs, localization abilities were poorer in all C&HPS conditions compared to the open ear condition. The C&HPS were not perceived as natural and resulted in right-left confusion as well as decreased response times (Talcott et al., 2012).

Lastly, Carmichel, Harris, and Story (2007) investigated the effects of localization abilities with HPDs. Each participant's localization abilities were evaluated in one of three HPD (R2000 Electronic Thin Muff, Pro-Ears Dimensions, or Action Ear Sport) conditions as well as an open ear condition. In this case, HPDs were shown to negatively

affect localization abilities and response times decreased but the effects were not significant when compared to the open ear condition (Carmichel et al., 2007). The talk-through capability and incorporation of amplitude processing on C&HPS have not been yet been studied.

Amplitude compression is used in C&HPS, primarily for the provision of hearing protection when sounds enter the device through the external microphones. The range in levels of sounds that enters the communication system (input) is larger than the range in levels that can safely be provided to the listener. If the signal for soft sounds is weak, some C&HPS will amplify those sounds, in order to make them audible to the wearer, an aspect of C&HPS referred to as hearing enhancement. If amplification of sounds was to be provided to the listener across the input range, the higher level sounds would become too high for the listener at the output. Amplitude compression allows for the presentation of a wider range of input levels without exposing the listeners to potentially hazardous sounds. Additionally, it allows for lesser degrees of distortion to the high level sounds than peak clipping.

Conclusion

The overall level differences between two sounds have been defined in the literature as the primary cue for relative auditory distance perception with secondary cues including the direct-to-reverberant ratio, the familiarity with the sound and spectral content of the stimulus. Amplitude compression is used in C&HPS in order to make all sounds audible and comfortable. There is limited information currently available on auditory spatial perception with C&HPS other than the examination of auditory localization through the hearing protection aspect. If the differences between overall level of sounds are reduced

through amplitude compression in C&HPS then relative auditory distance perception could be negatively affected. The focus of the present study was the effect of amplitude compression (similar to the amplitude compression results found for C&HPS A and C&HPS B) on relative auditory distance perception. Based on previously published studies in the area of auditory distance perception and what is known about amplitude compression, the following hypotheses were proposed:

1. Amplitude compression will reduce the differences in level between two sounds. This will negatively affect the jnd for separation such that larger separations will be required to accurately designate that two sounds are separate in space. The affect amplitude compression has on different levels between two sounds will increase with greater amounts of amplitude compression.

2. If the overall level is the primary cue for relative auditory distance perception, the jnd will remain constant across the two reference distances; otherwise, other cues will affect a listener's perception.

3. If the familiarity with a stimulus influences relative auditory distance perception, performance with the dog bark will be significantly better than that with the pink noise.

Chapter 3

Research Methodology

To evaluate the signal processing incorporated in C&HPS, recordings of the output through two commercially-available military C&HPS were made with a Knowles Electronics Manikin for Acoustic Research (KEMAR) located in the center of an anechoic chamber. KEMAR is an acoustic manikin designed to measure sounds as if they were presented to a human listener. Microphones located in the ear canals of the manikin simulate what would be received at the eardrum of a human listener. One-third octave narrow bands of noise with center frequencies of 500 Hz and 2000 Hz were presented at various levels from 50 to 100 dB SPL from a loudspeaker positioned directly in front of the KEMAR, labeled as 0 degrees. Figures 1 and 2 show the output levels for the two C&HPS systems across the range of input levels along with a solid reference line for linear signal processing. These figures are similar to what would be obtained from a hearing aid in an electroacoustic test box that allows for the determination of the presence or absence of amplitude compression in a hearing aid. In this case, the relationship between the input levels and the output levels was evaluated to determine the amplitude aspect of the C&HPS's signal processing. As seen in Figures 1 and 2, the input/output curves deviate from that projected for a linear system. The presence of amplitude compression is determined first through visual inspection to determine when the input/output function deviates from the linear reference. Amplitude compression was observed for both systems in the low and high frequencies.

Compression ratios were calculated from the figures as the difference in input divided by the differences in output relative to linear. As seen in Figure 1, for 500 Hz,

C&HPS A seems to be linear up to an input level of 75-80 dB SPL. After that point, it has compression with a ratio of 1.25:1. For 2000 Hz, C&HPS A begins to show compression around 65 dB SPL with a compression ratio of 1.5:1. A second level of compression begins around 90 dB SPL that exceeds 10:1. For C&HPS B (Figure 2), the system's amplification is linear until inputs of 80 and 85 dB SPL for the high and low frequencies, respectively. The high frequency range has a compression ratio of 3.0:1 and the low frequency range has a greater degree of compression, closer to 5.5:1. C&HPS A appears to provide amplitude compression over a larger range of inputs than C&HPS B. Furthermore, C&HPS B appears to provide amplitude compression primarily at the higher input levels presumably as output limiting to reduce distortion of high level sounds.

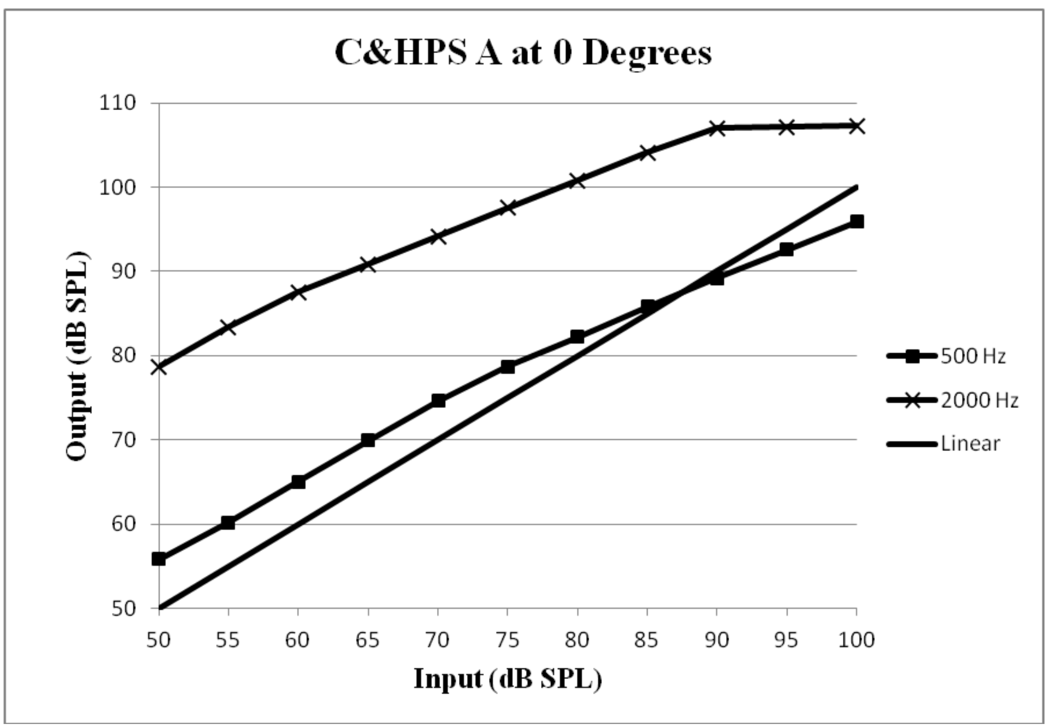

Figure 1. Input and output functions for C&HPS A at 0 degrees.

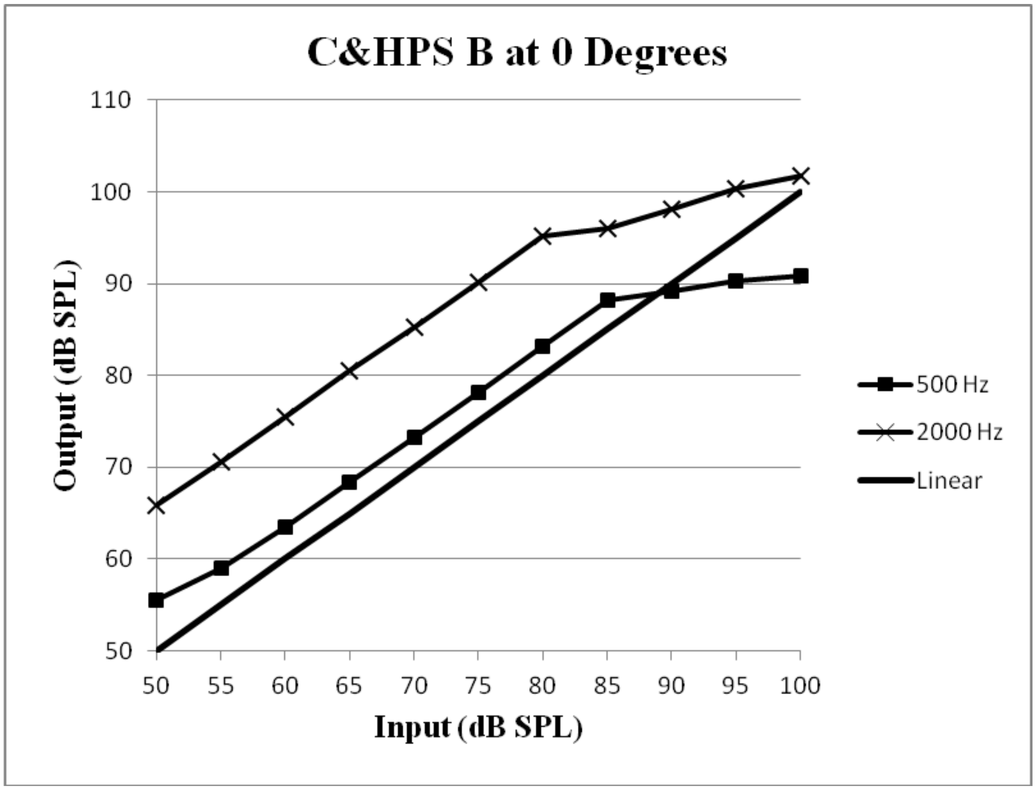

Figure 2. Input and output functions for C&HPS B at 0 degrees.

Impulse Response Recordings

Stereo recordings of an impulse stimulus were made through the KEMAR in a large sound treated room. The room was rectangular in shape and measured 70 ft long by 18 ft wide and 12 ft high. A diagram of the room can be seen in Figure 3. For this study the room was setup with fourteen fabricated plywood walls (seven on each side) with wooden legs attached to the bottom to simulate walls to create a hallway and to increase the reverberation values typically present in the space. The RT60 measured in the room when the room is empty is less than 400 ms (Scharine & Mermagen, 2008). The RT60 with the plywood walls present was approximately 600 ms. The plywood walls measured 4 ft wide by 8 ft tall and were 1/4 in thick. The distance between the walls was 14 ft.

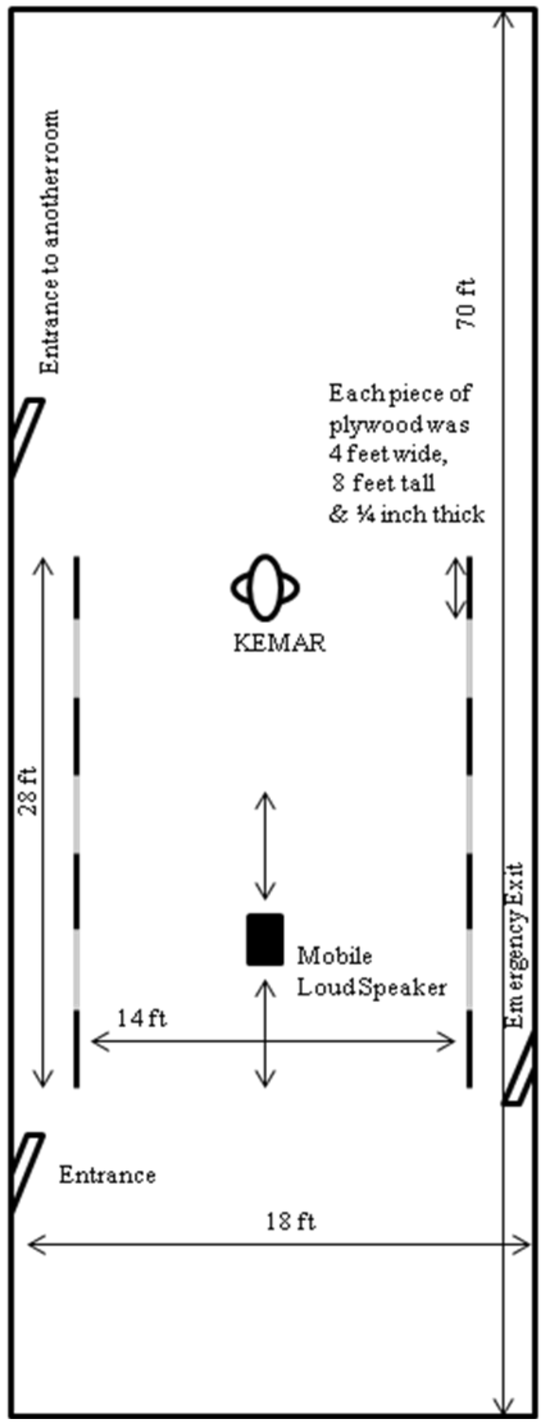

Figure 3. Diagram of the room in which the recordings were made.

KEMAR was positioned at one end of the fabricated hallway. The openings to the ear canals on KEMAR were positioned 76 in above the floor. Two microphone

preamplifiers were connected to KEMAR and set to the flat response mode. A Myer Sound MM-4XP loudspeaker was located on an adjustable loudspeaker stand with the center of the loudspeaker positioned 76 in above the floor.

The loudspeaker was positioned 36 in (3 ft) from KEMAR for the first recording and repositioned every 6 in on a linear path moving away from KEMAR for the remaining recordings. The final recording was made at 352 in (approximately 29 ft). Each time the loudspeaker was repositioned a laser pointer was attached to the front of the loudspeaker and shone onto the KEMAR nose to verify that KEMAR was in line with the loudspeaker. An impulse noise was played out of the loudspeaker at each distance and recorded through the ear canals of the KEMAR.

Convolution of Impulse Responses

The impulse response recordings were saved as stereo files in digital format. A computer engineer working at the U.S. Army Research Laboratory convolved two sounds with the impulse responses recorded from KEMAR using Matlab software: a burst of pink noise and a dog bark. The pink noise was selected as an unfamiliar sound based on previous literature (Coleman, 1962) and the dog bark was selected as a familiar sound. The waveforms and FFT analyses are shown in Figure 4.

The use of convolution of the stimuli with the binaural impulse responses recorded from KEMAR resulted in the application of ear specific head-related transfer functions (HRTFs) to the signals as recorded at the different distances. In essence, this process created two sets of stereo stimuli that were shaped in the same way they would have been if a listener had been located at the different distances within the space. The

use of a generic HRTF has been shown to provide adequate auditory perception for sounds within a space (Wenzel, Arruda, Kistler & Wightman, 1993).

Editing of Sound Files

A subset of the original recordings (78 to 276 in) was used in the present study. In order to edit the stimuli, the sound files were uploaded into Adobe Audition version 3.0. The longest sound file was determined to be 300 ms. All sound files were therefore edited to be 300 ms in duration prior to processing. The standardizing for duration was the only change made to the set of sound files that served as linear stimuli. Two copies of the sound files were then created for further processing for the amplitude compression schemes. Within both sets, the sound files were divided into two channels at 2000 Hz. Each channel had a unique compression ratio and compression threshold. For the set of stimuli used for the low compression condition, the compression kneepoint was set to 75 dB SPL with compression ratios of 1.25:1 for the low frequency channel and 1.5:1 for the high frequency channel. For the set of stimuli used for the high compression condition, the compression kneepoint was set to 85 dB SPL for the low frequency channel with a compression ratio of 5.5:1 and the kneepoint was set to 80 dB SPL for the high frequency channel with a compression ratio of 3:1. The attack time was set to 5 ms and the release time was set to 20 ms. Dillon (2001) reported these values as typical attack and release times in hearing aids. The setting selections of compression ratio and compression threshold values was an attempt to examine processing schemes similar to the two military C&HPS measured previously and shown in Figures 1 and 2. The resultant stimulus file sets were uploaded to a laptop computer with a custom computer program for data collection specifically created for this study.

Calibration

The stimulus levels to be presented to the participants through the laptop were calibrated prior to data collection. First, EAR TONE 3A insert earphones were connected to the laptop via the headphone port. An HA-1 coupler was connected to a Quest 1900 Sound Level Meter (set in fast/linear mode) and the EAR TONE 3A insert earphones were then connected to the HA-1 coupler. A 1000 Hz pure tone sound file was played on the laptop that had the same rms level of the farthest linear stimulus. The volume control on the laptop was adjusted until the farthest recording at 276 in reached the equivalent of 90 dB SPL. This resulted in the closest recording being presented at approximately 100 dB SPL for the linear condition. The volume control setting on the laptop was fixed in place and remained at this point for the duration of data collection. The volume setting was verified before each participant’s experimental session. Each participant was monitored to ensure the volume was not adjusted during the course of the study.

Dependent and Independent Variables

The dependent variable for the study was the jnd in in for the minimally detectable separation of two sounds. There were 12 conditions based on combinations of the three independent variables shown in Table 1; reference distance (6.5 ft and 16.5 ft), stimulus (burst of pink noise and a dog bark) and compression ratio (linear (none), low, and high).

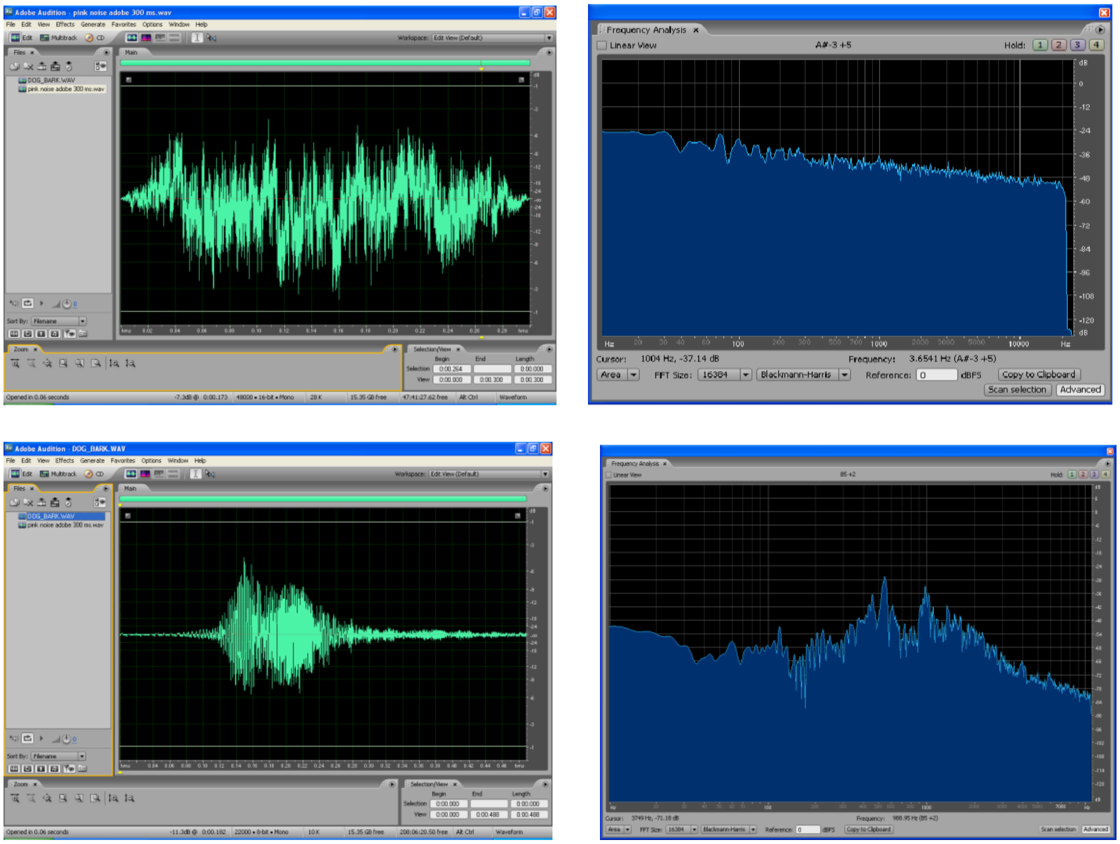

Figure 4. Top panel shows waveform and FFT analysis of the pink noise stimulus. Bottom panel shows waveform and FFT analysis of the dog bark Stimulus.

Table 1. Conditions for present study.

Stimulus	**Reference Distance**	**Compression Ratio**
Pink Noise	6.5 (ft)	Linear
		Low
		High
	16.5 (ft)	Linear
		Low
		High
Dog Bark	6.5 (ft)	Linear
		Low
		High
	16.5 (ft)	Linear
		Low
		High

Participants

Twenty-four adult participants (14 females and 10 males) ranging in age from 18-39 years (average age of 25) completed the study. Participants were recruited locally via word of mouth and flyers. A hearing screening using the Maico (MA-41) Portable Audiometer (last calibrated August 2012) confirmed air conduction hearing sensitivity was at or below 20 dB HL in each ear from 250- 8000 Hz (ASHA, 1997). Thresholds were confirmed to be at or below 20 dB HL in order to ensure participants were within the normal range of hearing (Schlauch & Nelson, 2009). Additional frequencies were screened compared to the ASHA (1997) screening guidelines due to the importance of frequency specific information. This study was approved by the Institutional Review Board for the Protection of Human Participants at Towson University and each participant signed an informed consent form; refer to Appendix A to review these documents.

Procedure

For data collection, participants were seated in a quiet room in front of a table with the laptop computer. EAR TONE 3A insert earphones were used to reduce the possibility for additional shaping of the stimuli to occur due to transmission through a listener's ear canals. Participants were shown a computer screen graphic that lead them through the steps involved in the study. For the duration of each trial, a question appeared at the top of the screen asking: Which sound was farther? Two rectangular buttons appeared on the lower portion of the screen: a button on the left labeled "sound 1" and a button on the right labeled "sound 2". There was also a button labeled "begin trial".

Participants used the mouse or the keyboard of the laptop to move the cursor and click on the buttons to begin a trial and to register a response. After the presentation of the two sounds within a trial, participants could take as long as they needed to determine which sound was farther but they were encouraged to respond in a reasonable amount of time. Total data collection time ranged from 90 minutes to 180 minutes per participant. This time was in addition to the completion of the consent form, hearing screening, and breaks taken by the participant.

Participants completed a minimum of three runs of a two-interval, two-alternative forced choice adaptive task for each condition (12 conditions). The reference distances were presented in a different order for each participant, minimizing the order effect. No feedback on accuracy was provided. The goal was to find the jnd (distance in in) at which a participant could detect that the two stimuli were separated and accurately identify which one was farther. The adaptive task followed the two down, one up rule in that after two correct responses, the separation distance between the two sounds was decreased but after one incorrect response, the separation distance between the two sounds was increased. Each run of trials started with the first trial presenting the reference stimulus with the associated starting point stimulus (in a random order) at their maximum separation. The associated starting point for the near reference distance of 78 in (6.5 ft) was 174 inches and the associated starting point for the far reference distance of 198 in (16.5 ft) was 276 in. Assuming the participant was able to correctly identify the larger separation between the two stimuli in the first trial, the program would then present stimuli that were closer to the reference stimulus using 12” steps until 3 reversals occurred. After 3 reversals, the step size was reduced to 6”.

The resultant threshold (calculated as the average separation distance of the last 8 reversals) within a given run represents the point at which the participant responded correctly 70.7% of the time (Levitt, 1971). At the end of a run, the computer program would calculate the threshold as the average of the last eight reversals along with the standard deviation of the reversals and this was provided to the experimenter in spreadsheet format. The runs were evaluated for the acceptance criterion and the corresponding thresholds were entered into a new spreadsheet. A run was considered acceptable if the standard deviation was ≤33% of the mean. After three runs, if the standard deviation across the run thresholds was ≤33% of the mean, data collection moved on to another condition. If not, additional runs were collected. Additional runs continued until either the standard deviation across runs ≤33% or a total of 5 runs were collected.

One unexpected event is worth noting. Approximately 33% of the participants were able to consistently distinguish the difference between two sounds at the smallest separation distance (6 in) in at least one run in at least one condition. In this case, the software was written to provide a threshold value of zero for that run since the program was unable to present a stimulus at a smaller separation distance more than the smallest step-size. In these cases, if the result was considered true and consistent, the minimum separation difference recorded in the spreadsheet to calculate across runs was six in rather than the value of zero provided by the software for that run. This occurred a total of 18 times, across 8 participants with no more than 2 runs per condition or a total of 4 runs across the experiment. The tallies for these instances are included in Appendix A.

Chapter 4

Results

There were two goals of the present study. The first was to determine the effect of amplitude compression (similar to the amplitude compression used in C&HPS A and C&HPS B) on relative auditory distance perception. The second goal was to determine if the jnd for sound source separation was different for sounds that are closer than for sounds that are farther away. The average jnd (in in) across each stimulus, distance, and compression is shown in Figure 5 for the pink noise stimulus and in Figure 6 for the dog bark stimulus. For both stimuli, the pink noise and dog bark, listeners needed increased separation between stimuli for the compressed conditions as opposed to the linear condition. Overall, listeners were better able to determine separation for sounds that were closer to them; however, the effects of reference distance and compression varied between the two stimuli. Amplitude compression affected relative distance perception greater for the close reference distance (6.5 ft) than the farther reference distance (16.5 ft) in the pink noise conditions. In the dog bark conditions the low level of compression had a greater effect at the closer reference distance than at the farther reference distance.

For both the pink noise stimulus and the dog bark stimulus, amplitude compression negatively affected a listener's relative auditory distance perception as shown by larger jnds in the compression conditions than in the linear condition. Namely, for higher levels of compression, a greater separation was needed between two sounds for a listener to accurately determine that they were separated in space.

A 3-factor repeated measures Analysis of Variance (ANOVA) was conducted with stimulus (pink noise, dog bark), distance (6.5 ft, 16.5 ft), and compression (linear,

low, high) as independent variables and the average just noticeable difference in in across runs per participant as the dependent variable. For all analyses, findings were considered significant at α=.05. All statistical analyses were carried out using SPSS v.19. Results of the 3-factor ANOVA showed no significant main effect of stimulus, however there were significant main effects of distance, $F(1,23)= 17.781$, $p<.001$ and compression, $F(2,46)= 68.869$, $p<.001$. Additionally, there were significant interactions between each pair of independent variables [stimulus x distance, $F(1,23)= 16.684$, $p<.001$, stimulus x compression, $F(2,46)= 19.094$, $p<.001$, and distance x compression, $F(2,46)= 5.542$, $p<.01$, as well as a significant interaction between all three independent variables, ($F(2, 26)= 9.251$, $p<.001$]. The three-way interaction is explained in that the effects of compression and distance were different within each of the two stimuli even though there was not a significant difference between the stimuli.

Next, two, 2-factor repeated measures ANOVAs were conducted, one on each of the two stimuli. For the pink noise stimulus, the results of the 2-factor ANOVA indicated a significant effect of distance, $F(1, 23)= 25.453$, $p<.001$, a significant effect of compression, $F(2,46)= 54.786$, $p<.001$, and a significant interaction between distance and compression, $F(2, 46)= 6.525$, $p<.01$.

To follow up the interaction between distance and compression for the pink noise stimulus, paired samples t-tests were conducted between each pair of compression levels within each distance. A bonferroni correction was applied for the six comparisons in order to adjust for multiple comparisons (Howell, 2002). The bonferroni formula is α/k, therefore, the alpha level of .05 was divided by k which was six conditions, resulting in a new alpha level of .008. The Bonferroni correction was applied in order to control for the

potential for an elevated familywise error rate due to multiple comparisons. For the pink noise stimulus, the following pairwise comparisons were significant for the closer distance, low versus high compression, $t(23)=6.696$, $p<.008$, linear versus high compression, $t(23)=7.866$, $p<.008$. For the farther condition, there were significant differences between the low verses high compression, $t(23)=3.518$, $p<.008$ and between the linear and high compression, $t(23)= 5.59$, $p<.008$. However, there was no significant difference between the linear and low compression levels for the closer and farther reference conditions. These results indicated that for the pink noise stimulus, compression significantly affected the listener's ability to perceive separation. However, for the farther reference, initial amounts of compression were not sufficient to alter performance since performance was not significantly different between the linear and low compression conditions.

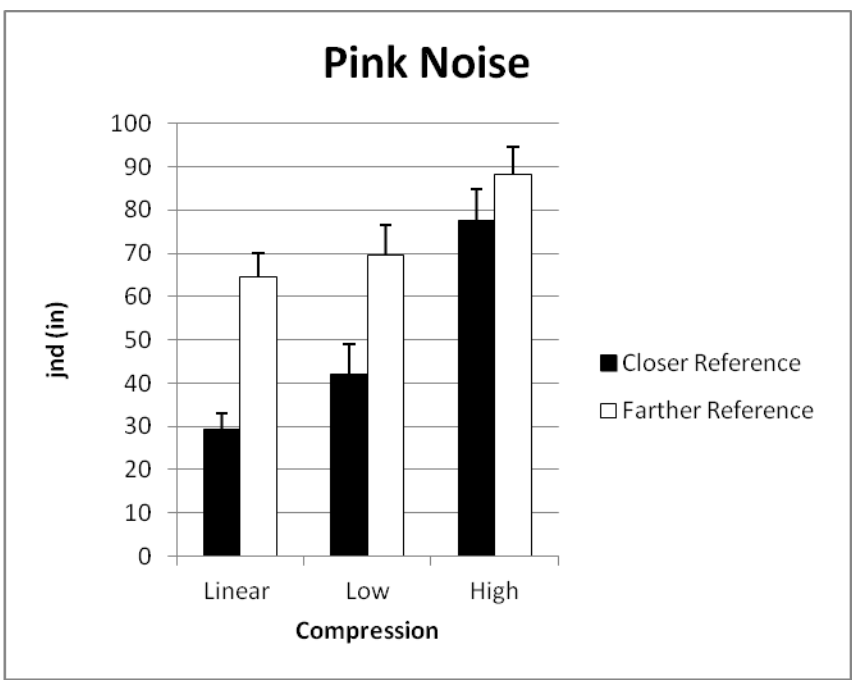

Figure 5. Average jnd (in in) needed for each condition with the pink noise stimulus. Error bars indicate +1 standard error.

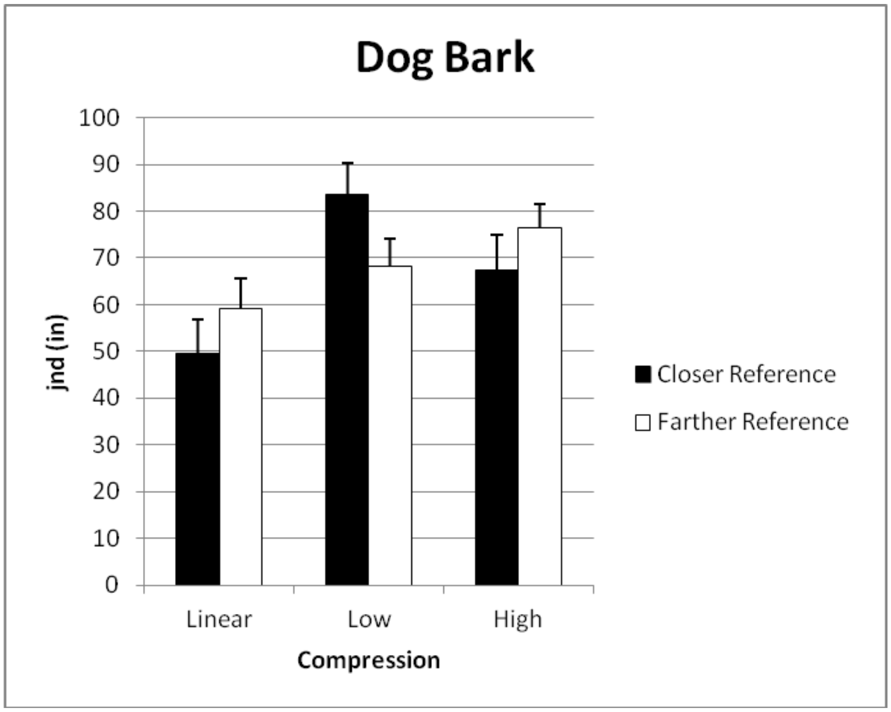

Figure 6. Average jnd (in in) needed for each condition with the dog bark stimulus. Error bars indicate +1 standard error.

For the dog bark stimulus, the results of the 2-factor ANOVA indicated a significant effect of compression, $F(2, 46)= 25.316$, $p<.001$, as well as a significant interaction between distance and compression, $F(2, 46)= 8.018$, $p<.01$. There was no significant effect of distance.

To follow up the interaction between distance and compression for the dog bark stimulus, paired samples t-tests were conducted between each pair of compression levels within each reference distance. A bonferroni correction was also applied for the six comparisons for the dog bark stimulus (Howell, 2002). For the dog bark stimulus, the following pairwise comparisons were significant for the closer distance, linear versus low compression, $t(23)=5.522$, $p<.008$, and linear versus high compression, $t(23)=3.095$,

$p<.008$. For the farther distance the following pairwise comparisons were significant, low versus high compression, $t(23)=2.925$, $p<.008$, and linear versus high compression, $t(23)=4.706$, $p<.008$]. The interaction can be explained by the change in the direction of the differences for the reference distances within the low level of compression. Namely, for the farther reference distance, there is a steady increase in jnd with increasing amounts of compression. For the closer reference distance, there is a larger effect of the low amount of compression on jnd than the high amount of compression as compared to the linear condition.

In order to compare the current findings to other studies, Weber's ratios were calculated for average thresholds within each condition. To calculate the Weber ratio, the average threshold (in in) obtained for each condition was divided by the reference distance in in. For instance, if the average jnd threshold for the close reference was 49.67 in it was divided by the reference distance of 78 in, resulting in a Weber ratio of 63.68%. Table 2 shows Weber ratios for the two reference points and conditions along with those reported from other studies.

Table 2. Weber ratios for all conditions of the present study.

Condition	Distance (m)	% of jnd (Weber's Ratio)
Dog Bark (linear)	1.98	63.67%
Dog Bark (linear)	5.02	29.86%
Pink Noise (linear)	1.98	37.73%
Pink Noise (linear)	5.02	32.54%
Dog Bark (low compression)	1.98	107.08%
Dog Bark (low compression)	5.02	34.39%
Pink Noise (low compression)	1.98	54.06%
Pink Noise (low compression)	5.02	35.11%
Dog Bark (high compression)	1.98	86.38%
Dog Bark (high compression)	5.02	38.62%
Pink Noise (high compression)	1.98	99.38%
Pink Noise (high compression)	5.02	44.48%

Chapter 5

Discussion

There are many situations where accurately perceiving distance is critical. Individuals in the military often need to know the location of artillery fire, firefighters often need to know the location of individuals in burning buildings, and parents often need to gauge the distance of various sounds to keep their children out of danger. When individuals make distance perception judgments they use stimulus characteristics such as sound level, reverberation, frequency spectrum, and their familiarity with the stimulus (Coleman, 1963; Mershon & King, 1975). The purposes of this study were: (1) to determine if amplitude compression has an effect on relative auditory distance perception, (2) to determine if individuals could perceive the relative separation of stimuli that are closer to them differently than stimuli that are further away, and (3) to determine if familiarity with a stimulus would contribute to differences in relative auditory distance perception.

The present study examined the effects of amplitude compression on relative auditory distance perception. Amplitude compression decreases the level intensity differences between two sounds and makes it more difficult for a listener to distinguish that they are separated in space. Therefore, a larger jnd should be expected in conditions where amplitude compression is included in the signal processing. A condition of linear processing (no compression) was included for a baseline measure for comparisons to performance in compression conditions and to be able to compare to findings published in the literature. It is clear that amplitude compression negatively affected relative

auditory distance perception in the present study through changes in level differences but additional cues may also contribute to the findings.

Comparison to the Literature

There is only one condition that can be compared to previously published findings, and that is the linear condition. In order to compare the current findings to other studies, Weber's ratios were calculated for average thresholds within each condition. Weber ratios for all conditions for the present study can be seen in Table 2 in the results section. Table 3 shows Weber ratios for the linear condition at the two reference points along with those reported from other studies. In general, listeners needed increased separation between stimuli as the compression level increased for the pink noise. The effect of amplitude compression was greater for the closer reference distance (6.5 ft) than the farther reference distance (16.5 ft). In the dog bark conditions amplitude compression negatively affected the jnds with the low level of compression having a greater effect at the closer reference distance than at the farther reference distance. For both stimuli, amplitude compression negatively affected a listener's relative auditory distance perception.

As previously mentioned Stybel and Perrott (1984) reported a jnd for distance of 9% for a reference distance of 3 m and a jnd for distance of approximately 6% for reference points ranging from 6-49 m. The pattern found for relative auditory distance perception by Strybel and Perrott (1984) suggested that for closer reference distances the jnd threshold will be larger than when for the farther reference distance. The pattern found by Ashmead et al (1990) suggested a jnd of 6% at both 1 and 2 m. Coleman (1962; 1963) suggested that the jnd remains constant across reference distances and should be

5%. The significant effect of reference distance found in the overall 3- factor ANOVA of the present study indicates that overall, jnd increased with increases in reference distance. The interaction between reference distance and stimulus shows that the pattern differs between the two stimuli. For the pink noise stimulus, there is a larger difference in jnd at the linear condition which decreases with additions of compression. The effect of reference distance is less clear with the dog bark stimulus due to the change in pattern with the low level of compression.

Table 3. Weber ratios for present study (linear conditions) and the literature.

Study	Distance (m)	% of jnd (Weber's Ratio)
Stybel and Perrott (1984)	3.04	9 %
Stybel and Perrott (1984)	6-49	6 %
Stybel and Perrott (1984)	.49	19%
Stybel and Perrott (1984)	1.52	11%
Ashmead et al. (1990)	1	5.73%
Ashmead et al. (1990)	2	5.91%
Present Study: Dog Bark (linear)	1.98	63.68%
Present Study: Dog Bark (linear)	5.02	29.86%
Present Study: Pink Noise (linear)	1.98	37.73%
Present Study: Pink Noise (linear)	5.02	32.54%

The closer reference point of 78 in is similar to the research that has been done at 1.5-2 m. A Weber ratio for the closer reference was calculated for the linear condition in the present study at 78 in at 63.68% for the dog bark stimulus and 37.72% for the pink noise stimulus. Ashmead et al. (1990) used a broadband noise stimulus at 2 m and found a Weber ratio of 5.91%. Stybel and Perrott (1984) used a broadband noise stimulus at 1.52 m and found a Weber ratio of 19%.

The results from the present study differ substantially from those of previous research. One possible explanation for the differences in results is that the environment used in the present study is reverberant as compared to the anechoic environments from

previous work. Possible reasons for differences between the results found in the present study and previous research are explored below.

Reverberation

It is important to consider the environments in which the data for the different studies were collected. The present study used a fabricated plywood hallway with reverberant surfaces whereas the previous studies used environments that were relatively low in reverberation. Ashmead et al. (1990) collected data in an anechoic chamber and Stybel and Perrott (1984) collected data on an athletic field with the participants seated on an elevated platform. Previous research provides data for environments that were low in reverberation.

In anechoic environments the intensity level decreases quickly with reverberation and in a reverberant environment the intensity level decreases slower due to reflections continually adding energy to the sound. The smaller decreases in energy could provide a false cue to the listener. It is reasonable to conclude that reverberation may have had a substantial effect on the listeners' ability to determine the separation of two sounds. Reverberation present in the room may have smeared distance information that would have been available to listeners in a less reverberant room. No firm conclusion can be made on the effect of reverberation itself based on the results presented here because no data were collected to comparison listener performance between anechoic and reverberant environments.

Familiarity of Stimulus

The decision to use two different stimuli (a familiar sound, the dog bark and an unfamiliar sound, the broadband pink noise) was to explore the influence of familiarity

reported in previous studies. Coleman (1962) and Mershon and King (1975) suggested that a listener's familiarity or experience with a stimulus improves their ability to accurately determine its distance in space. The dog bark stimulus was thought to be a familiar sound as compared to the pink noise. Therefore individuals were thought to perceive distance better (with less distance between the two sounds needed) for the dog bark stimulus than for the pink noise; however, overall this was not the case. For this study, there was no significant difference in jnd found between the two stimuli.

However, when examining the differential effects of compression on jnd, it appears that both stimuli were affected and the effects of compression on the pink noise stimulus were more systematic than the dog bark. For the pink noise stimulus, changes in compression ratio resulted in corresponding changes in jnd. For the dog bark stimulus, although there was an initial effect of compression, additional compression yielded smaller changes in jnd. It is possible that the listener's familiarity with the dog bark allowed them to maintain the jnd across greater amounts of compression.

Frequency Spectrum

Frequency spectrum is a cue used for auditory distance perception. Coleman (1968) suggested that the frequency spectrum of a sound will change as the sound wave travels over distance. Blauert (2001) suggested that sound absorption of high frequency information will only occur for distances greater than 15 m where acoustic absorption can play a role. The present study did not investigate distances greater than 15 m. The present study only investigated 2 m and 5 m. Therefore, assuming Blauert (2001) is correct the changes in the frequency spectrum were not likely a contributing factor in the present study.

C&HPS

As previously mentioned, the compression settings applied to the stimuli were selected to be similar to what was measured in two military C&HPS. Although the compression selections were not exact matches of the C&HPS, they were intended to be similar to them. Individuals performed poorer in the high compression ratio, C&HPS B, for the pink noise condition. This should be taken into consideration when using these communication systems. The larger amount of compression resulted in listeners needing larger separations between two sounds in order to tell that the two sounds were originating from different distances. This could be important for individuals in the military or police officers using them during duty. Perhaps lower levels of compression are better since it allowed for listeners to detect a separation of two sounds with a smaller distance. Alternatively, higher compression ratios may be acceptable for high level sounds, assuming most sounds heard would be less than the compression threshold.

Limitations

There are several factors that may indicate why there is a difference in results from this study compared to results from the literature. First, the methodology and equipment utilized for the present study is much different compared to earlier research conducted, with the earliest research being 66 years ago. For the present study, recordings were made and played back through a computer using insert earphones. Previous studies like the Ashmead et al. (1991) study played one stimulus from a loudspeaker and then physically moved the loudspeaker in order to play the second stimulus. The listeners were immersed in the actual environment in these cases and could have gained some sense of physical space and probable distance from this.

Previous studies were conducted in anechoic environments whereas the present study was developed with reverberation. The presence of reverberation could have contributed to the larger separation distances needed in the present study. Repeated exposures to a stimulus could allow for the listener to fine tune their judgments regarding sound separation in previous studies whereas in the present study only a single instance of a set of sounds was presented. In addition, the present study did not make an attempt to examine effects of reverberation. In order to do that a non-reverberant environment would need to be used.

Conclusion

It is critical for individuals to accurately perceive relative auditory distance. Individuals in the military need to know the location of artillery fire, firefighters need to know the location of individuals in burning buildings, and mothers need to gauge various sounds in order to keep their children out of danger. These individuals make distance perception judgments by using stimulus and environmental characteristics such as sound level, reverberation, frequency spectrum and their familiarity with the stimulus (Coleman, 1963; Mershon & King, 1975). The purpose of this study was to determine if individuals can perceive the relative perception between stimuli that are closer to them better than stimuli that are further away, to determine if familiarity with stimulus would effect perception, and to determine if amplitude compression affects relative auditory distance perception.

Performance was evaluated across two stimuli for two reference distances of 6.5 ft and 16.5 ft and three processing schemes (none (linear), low, and high amplitude compression). For both stimuli, amplitude compression significantly affected the

minimum separation distance needed for accurate relative auditory distance perception. For the pink noise stimulus, listeners needed a systematic increase in separation as the compression level increased. The effect of compression was greater for the close (6.5 ft) distance than the far (16.5 ft) reference distance. For the dog bark stimulus, compression significantly affected performance. Furthermore, the low level of compression had a greater effect at the closer reference distance than at the farther reference distance. For both stimuli, amplitude compression negatively affected a listener's relative auditory distance perception. For higher levels of compression, a greater separation was needed between two sounds for a listener to accurately determine that they were separated in space.

Future studies in this area should examine a larger more diverse sample size such as individuals with hearing loss, individuals of various age ranges, and investigate a larger distance for the further distance condition. Further, the effects of practice and training should be explored to determine if initial degradation in relative auditory distance perception can be reduced over time.

Appendices

Appendix A

TOWSON
UNIVERSITY

APPROVAL NUMBER: 12-A079

To: Ashley Foots
P.O. Box 531
Rising Sun MD 21911

From: Institutional Review Board for the Proctection of Human Subjects, Patricia Alt, Member PA/WMP

Date: Tuesday, July 03, 2012

RE: Application for Approval of Research Involving the Use of Human Participants

APPROVED
JUL 5 2012
PA/WMP
TOWSON IRB

Office of University
Research Services

Towson University
8000 York Road
Towson, MD 21252-0001

t. 410 704-2236
f. 410 704-4494

Thank you for submitting an Application for Approval of Research Involving the Use of Human Participants to the Institutional Review Board for the Protection of Human Participants (IRB) at Towson University. The IRB hereby approves your proposal titled:

Effects of Compression on Relative Auditory Distance Perception

If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should your research extend beyond one year in duration, or should there be substantive changes in your research protocol, you will need to submit another application for approval at that time.
We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: S. Pallett
File

TOWSON
UNIVERSITY

Date: Tuesday, July 03, 2012

NOTICE OF APPROVAL

TO: Ashley Foots **DEPT:** ASLD

PROJECT TITLE: *Effects of Compression on Relative Auditory Distance Perception*

SPONSORING AGENCY:

APPROVAL NUMBER: 12-A079

The Institutional Review Board for the Protection of Human Participants has approved the project described above. Approval was based on the descriptive material and procedures you submitted for review. Should any changes be made in your procedures, or if you should encounter any new risks, reactions, injuries, or deaths of persons as participants, you must notify the Board.

A consent form: [✓] is [ ] is not required of each participant

Assent: [ ] is [ ] is not required of each participant

This protocol was first approved on: 03-Jul-2012
This research will be reviewed every year from the date of first approval.

Patricia Alt

Patricia Alt, Member
Towson University Institutional Review Board
WP

TOWSON UNIVERSITY

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INFORMED CONSENT FORM

Title of Investigation:
Effects of Compression on Relative Auditory Distance Perception

Principle Investigator: Ashley Foots, B.S.
Doctor of Audiology (Au.D.) Candidate
Towson University
(410) 309-2126

Thesis Chair: Steve Pallett Au.D., CCC-A
155 Stephens Annex
Towson University
Dept. of Audiology, Speech-Language Pathology and Deaf Studies
8000 York Road
Towson, Maryland 21252-0001
(410) 704-3620

Purpose of the Study:

The purpose of the present study is to investigate the effect of minimizing differences in loudness of two sounds on a listener's ability to determine which sound is farther away from them in space.

Procedures:

Your role in this study will consist of attending one two-hour experimental session. At this session, you will first have a hearing screening completed. You will then wear headphones to listen to stimuli and use a computer to select which of two stimuli was farther away. In order to participant in this study, you must be willing to sign this informed consent document.

Following the hearing test, you will complete several trials of determining which of two stimuli is farther away.

All testing will take place in a Van Bokkelen Hall quiet room. All audiological testing will be completed by a Doctor of Audiology (Au.D.) candidate, under the direct supervision of her thesis chair, Dr. Steve Pallett. Dr. Pallett is an Audiologist who holds a Certificate of Clinical Competence from the American Speech-Language-Hearing Association (ASHA) and holds a valid License in the State of Maryland.

Benefits:

It is hoped that the results of this study will provide information that may better help to assess an individual's potential to estimate distance perception with compressions signals.

Risks:

There are no known risks associated with participation in this study. Standard audiological testing will be employed. The sound intensity levels will be carefully monitored and will be no louder than your

most comfortable listening level. Should the assessment become distressing to you, it will be terminated immediately.

Cost Compensation:

1. You will receive a free hearing test as a part of this study.
2. You will receive free parking for each visit.
3. There will be no monetary remuneration for participating in this study.

Rights as a Participant:

1. Your participation in this study will remain strictly confidential. Only the principle investigator and her supervisor will have access to the identities of the participants and information associated with their identities. Any data collected through the computer system will be labeled using a code number, which will be randomly assigned to the subject. This computer will be password protected. Although the information may be published or presented, at no time will identifying information regarding participants be used.
2. Participation in this study is voluntary. At any time prior to or during the study, you are free to discontinue participation. A decision not to participate or to withdraw from the study will have no effect on your status or any current or future services you may be receiving at Towson University.
3. You are free to ask questions regarding the study and/or the test procedures. These questions will be answered by the investigator.
4. If you have any questions or problems that arise in connection with your participation in this study, please contact Ashley Foots, the principle investigator of this study at (443) 309-2126 or Dr. Patricia Alt, Chairperson of the Institutional Review Board for the Protection of Human Participants at Towson University at (410) 704-2236.

Informed Consent:

_____ I have read and understood the information on this form.

_____ I have had the information on this form explained to me.

________________________________ ________________________________
Participant's Signature Date

________________________________ ________________________________
Witness to Consent Procedures** Date

________________________________ ________________________________
Principle Investigator Date

**If investigator is not the person who will witness participant's signature, then the person administering the informed consent should write his/her name and title on the "witness" line.

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY.

IRB Approval Number: *12-A079*

Appendix B

This table displays the participants and conditions in which zero values were recorded.

			Participant								
Stimulus	Distance	Compression	2	6	14	16	18	20	22	24	total
Dog Bark	Closer Reference	Linear		2		2					4
		Low									0
		High									0
	Farther Reference	Linear									0
		Low									0
		High			1						1
Pink Noise	Closer Reference	Linear		1	2			2		1	6
		Low		1			1				2
		High				1			1		2
	Farther Reference	Linear					1				1
		Low	2								2
		High									0
		Totals	2	4	3	3	2	2	1	1	18

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CURRICULUM VITA

Ashley Foots
P.O. Box 531
Rising Sun, MD 21911

Doctor of Audiology (Au.D.), May 2014

Education:
Towson University- Towson, MD
Doctorate of Audiology (Au.D.), August 2010- Present
Anticipated graduation: May 2014

Towson University- Towson, MD
Bachelor of Science in Speech-Language Pathology/Audiology, May 2010

Clinical Experience:

Baltimore Veterans Medical Center- Baltimore, MD
  Audiology Student Clinician, January 2013- May 2013
ENTAA Care- Glen Burnie & Annapolis, MD
  Audiology Student Clinician, September 2012- December 2012
Hearing and Speech Agency- Baltimore, MD
  Audiology Student Clinician, June 2012- July 2012
Sonus Hearing Care- York, PA
  Audiology Student Clinician, January 2012- May 2012
Towson University Speech, Language and Hearing Center- Towson, MD
  Audiology Student Clinician, September 2010- December 2011

Publications & Presentations:

Henry, P. & Foots, A. (2013, Apr.). Effects of compression on relative auditory distance perception. Poster presentation at AudiologyNOW! 2013, Anaheim, CA.

Henry, P. & Foots, A. (2012). Comparison of User Volume Control Settings for Portable Music Players with Three Earphone Configurations in Quiet and Noisy Environments. *Journal of the American Academy of Audiology, 23,* 182-191.

Henry, P. & Foots, A. (2011, Apr.). Auditory Localization with Fleece Caps and Hooded Jackets. Poster presentation at AudiologyNOW! 2011, Chicago, IL.

Henry, P. & Foots, A. (2010, Apr.). Attenuation Reduces Listening Levels for Music in Noise. Poster presentation at AudiologyNOW! 2010 (annual convention for the American Academy of Audiology), San Diego, CA.

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